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Measurement of the acoustical performance of traditional vernacular mosques in Malaysia

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ABSTRACT

Mosques are worship places used for activities performed by Muslim e.g. prayer, speech and Quran recitations. All activities in the mosques are important acoustical interests for satisfactory speech intelligibility i.e. verbal communication. Unfortunately, recent architectural styles or restoration works were given very little attention about acoustical considerations. In this research, the acoustical performance of five selected traditional vernacular mosques in Malaysia, built between 1728 – 1830, have been investigated as a preliminary study. The acoustic parameters such as reverberation time (RT), clarity (C50) and speech transmission index (STI) were measured. Measurement of the influence of the operating facilities in the mosques on their acoustic quality was also carried out. The PC-based measuring system (dBBati32) with sound level meter (01dB Solo Metravib) as analyzer was utilized. Data collected reveals initial findings that the operating facilities in the mosques resulting higher rating of noise criteria which is reducing the performance of speech intelligibility.

Keywords: Mosque, Acoustic quality, Measurement

1. INTRODUCTION

Study within the boundaries of mosque art and architecture has turned to be an eminent subject among scholars [1-3]. Valuable information was captured and used for the enhancement and evolvement of Muslim religious buildings. After the demise of Prophet Muhammad ﷺ, the administration of the Muslims and Islam in general, including the administration of mosque buildings were taken over by his four companions and then by a number of Islamic dynasties such as the Ummayad, Abbasid, Fatimids, Safavids, Ottoman and many more. Even though the leadership of Islam and the architecture of mosques changed over time, the basic components inside the *zulla* (main prayer hall) remained the same with a few components being added following the needs of the believers during the period of that particular mosque was built.

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Meanwhile, a number of studies [4-8] has been conducted in order to check the acoustical characteristic of mosques. Hammad [4] presented evaluation of speech intelligibility in mosques in Amman, Jordan and concluded the acoustical characteristics of mosques had been neglected. In Saudi Arabia, 21 extensive field measurements of mosques were carried out in order to characterize their acoustical quality and to identify the impact of active environment control systems [5]. However, limited numbers of studies have been conducted in Malaysia. Dimon, M.N. *et al* highlighted the compilation of contemporary issues of mosques acoustics including optimization of the reverberation time and acceptable Speech Transmission Index (STI) [8].

Focusing on traditional vernacular mosques in Malaysia, our preliminary objectives of this paper are: (i) to investigate the impact of the environmental aspect and mechanical services system e.g. fans incorporated into mosque designs on acoustical quality; and (ii) to investigate acoustics performance of the main hall design of the mosque.

2. ASSESSMENT OF ACOUSTICAL QUALITY IN MOSQUES

Recently, several evaluations have been constructed for speech signals to the listener in enclosures can be explained by contemporary room-acoustic indicators. In difficult acoustic conditions e.g. church [9-10], the assessment of loudspeakers or sound reinforcement system (SRS) is often used for evaluation. One of the important acoustical interests for satisfactory speech intelligibility is verbal communication. Having same similarity acoustical interest of the church, all activities in the mosques such as prayer, public speaking, preaching, lecturing and *Quran* recitations is related to speech intelligibility. Speech intelligibility (SI) is the accuracy with a normal listener can understand a spoken clarity of word or phrase. The intelligibility of speech in enclosure is measured in the presence of distortion in speech signal caused by noise in transmission path. It also can be influenced by the, ambient background noise (BN), and the reverberation time (RT) of the enclosure. The facilities in operation in mosques e.g. fans, air-condition, indoor noise, etc will attributed to poor acoustical performance of the enclosure. Therefore, Noise Criterion (NC rating), was developed for wider application to evaluate the permissible value obtained in the room or enclosure. On the hand, the evaluation of clarity (C_{50}) and speech transmission index (STI) also need to take into consideration for representing good intelligibility in a room measured.

3. METHODOLOGY

First stage of this investigation was selection of sample of representative of the traditional vernacular mosques in Malaysia. Five mosques were selected. The selection based on the following: general information of mosque and plan layout. The mosque shape, size, spatial arrangement and other factors contributed to the final selection in addition to mosque accessibility. Out of total 37 mosques, five (i.e. an approximately 14%) were selected for acoustical measurement.

3.1 Sample mosques

The mosque volume is important parameter influencing the acoustical characteristics. Table 1 presents data summarizing the main physical characteristics of the five chosen mosques. It includes information such as mosque's length, width, height, volume and expected capacity when full occupied. However, only measurements of the main halls were recorded.

The selected main halls varied from very small with 215 m^3 and capacity of as few as 75 worshippers to large volumes over 1000 m^3 and a capacity of over 400 worshippers. Actual capacities of each mosque are expected to increase if all areas (i.e. verandah) in the mosques were occupied, such as during Friday prayer.

Five mosques were selected as the case study, two in George Town and three in Melaka World Heritage Sites.

3.1.1 Case Study 1: Masjid Lebuh Aceh (LA), George Town

Masjid Lebuh Acheh was built in 1808 by a member of a Royal family from Acheh, Sumatera. When Muslim settlements sprawled in Lebuh Acheh, they invited more Malays from around the peninsular and created a center of Islamic religious study within the vicinity of the Mosque. Consequently, the surrounding area began to develop in line with the growing number of merchants and traders coming from all over Malaysia (or Malaya then), the Arabian Peninsula (Middle-East) and India. The mosque is rectangular in plan; the main hall has three front doors, four side doors, six side

Table 1 - Summary of main physical characteristics of the selected sample mosques

No.	Mosques	Mosque Code	On-site measurements			Calculated parameter Nature of Practice	
			Dimensions of hall (m)			Volume (V) m^3	Expected capacity
			L	W	H		
1	Masjid Lebuh Acheh	LA	17.10	13.62	4.30	1001.5	410
2	Masjid Batu Uban	BU	7.40	7.45	3.90	215.0	75
3	Masjid Tengkera	MT	14.20	13.50	4.10	786.0	300
4	Masjid Kg Duyong	KD	11.80	8.40	4.20	413.3	256
5	Masjid Kg Keling	KK	15.80	13.25	4.60	963.0	393

windows and another two windows on the qibla wall. The wall is of brick plastered with lime, floor is carpeted and the ceiling is painted timber strip and with six free standing columns.

3.1.2 Case Study 2: Masjid Batu Uban (BU), George Town

This mosque is said to be built in 1734 by the Malays from Buadi Village, Paya Kumbu, Sumatera. It started as a *surau* (musolla) then turned into a mosque when the Muslims increased and formed a settlement. It was also used as a transit point for Muslim traders from India, Pakistan and Middle-east. Similar to other vernacular mosques, the floor plan of Masjid Batu Uban is almost square in shape. There are four columns in the middle of prayer hall to support the pyramidal roof structure and six side windows.

3.1.3 Case Study 3: Masjid Tengkera (MT), Melaka

Masjid Tengkerah is recorded as the oldest mosque in Malaysia, built in 1728 with a hybrid design of *Nusantara* and Chinese architecture. The square plan mosque consists of main prayer hall and terrace, covered with three layers of pyramidal roof. Six free standing columns supporting the roof structure. Similar to Lebuh Aceh mosque Tengkera Mosque is also of brick and plastered with lime, carpeted and timber strips ceiling.

3.1.4 Case Study 4: Masjid Kg. Duyong (KD), Melaka

Kampung Duyung Mosque is recorded to be built in 1850 and the mosque has faced a few renovations. In spite of the renovations, the original structure and design still remains as close as possible to the original. The pyramidal three layer roof shape was once finished with imported tiles mainly from China. The China tiles were ruined and changed totally with local tiles in 1967. The floor plan of the mosque is almost square and similar to other vernacular mosques in Melaka, there are four columns erected in the middle of the prayer hall supporting the pyramidal roof on top. Main entrance of the mosque leads the users to the prayer hall directly facing the Qibla direction.

3.1.5 Case Study 5: Masjid Kg. Keling (KK), Melaka

Masjid Kampung Keling is situated in the middle of Melaka Heritage trail. "Keling" refers to the Southern Indian folks who married the local Malays. Built in 1748, this mosque was renovated in 1908, with the original structure and design well kept. The roof shape and structure of the mosque gives it the vernacular look; that is pyramidal. Still, some of the interior design and detailing carry influences from British and Dutch architecture. Similar to Tengkera and other mosques with pyramidal roof structure, the shape of the floor plan is almost square with four columns in the middle of the prayer hall. There are two main entrances to the prayer hall; one is directly opposite of the Qibla wall and the other is adjacent to the ablution pool. The prayer hall is surrounded by verandahs on each side except on the Qibla wall side.

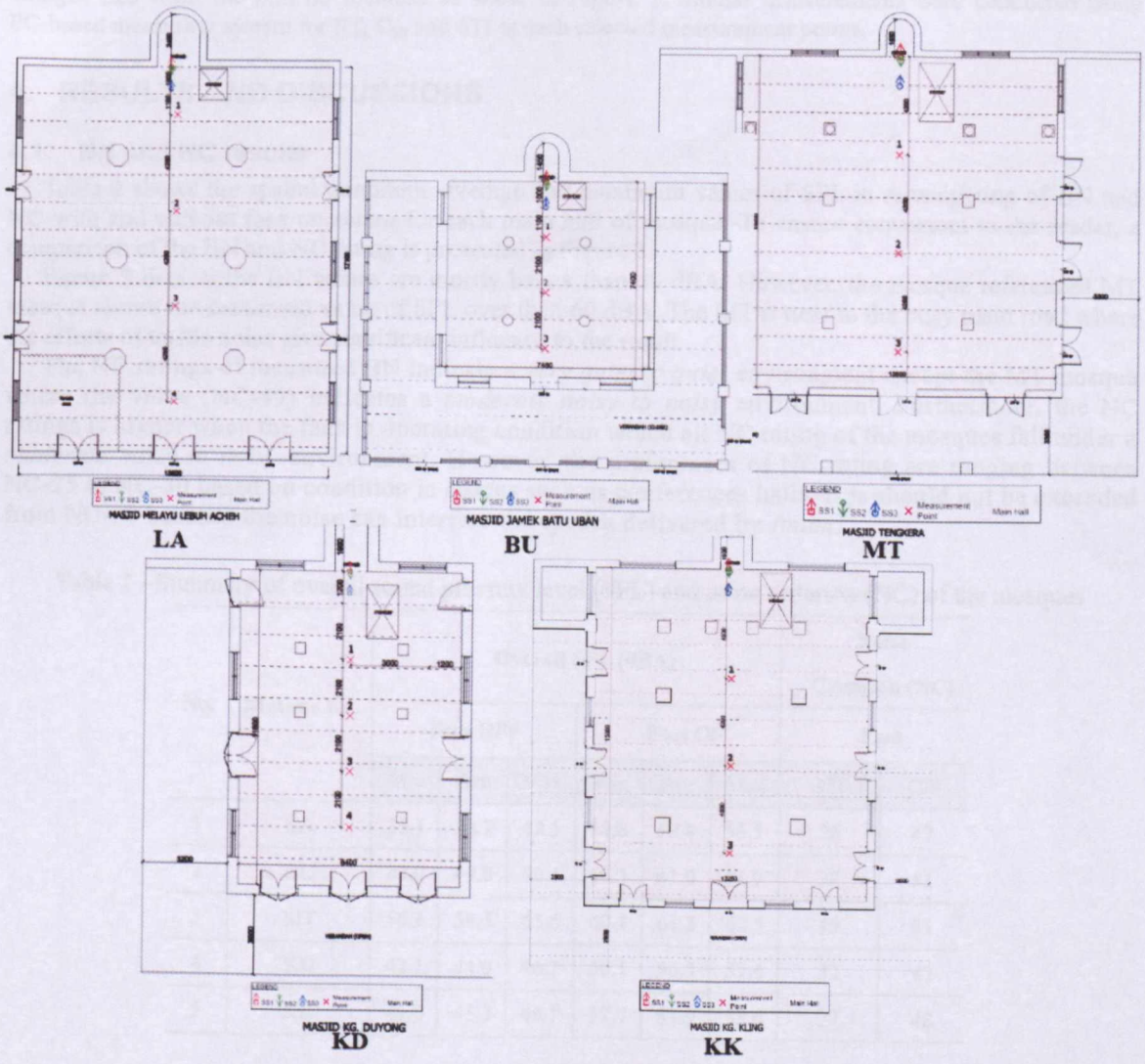

Figure 1 - Plan layouts with measurement point's location.

3.2 Measurement procedures

To evaluate the acoustical characteristics of the selected unoccupied mosques, the PC-based acoustic measuring system and analyser was utilized. The PC-based measuring system (dBBati32) was integrated with sound level meter (01dB Solo Metravib) as analyser. Based on shape and floor area of each selected mosque, an adequate number of listener positions were chosen for measurement to achieve sufficient coverage of the main hall floor area. It was necessary to measure the mosque BN and subsequently determine the NC rating. The 1/1 octave band setting of BN (dBA) was measured at each selected measurement points using sound level meter (Cirrus). The sound level meter was located 1.4 m above the floor. Time length every 10 sec is employed for one minute and a series of SPL are extracted using commercial software (dBBATI32). So as to provide compact presentation, the SPL is calculated and averaged.

For NC measurement, same measurement was conducted with all ceiling and wall fans operating. A wind screen was used to reduce the effect of airflow due to the operation of fans. The intention of conducting this measurement is to ensure the volume controls were kept remains without any alteration. To check the effect of the main hall design in acoustical quality, the positioning (SS1) of the small loudspeaker (BOSE) was used to radiate incoherent pink noises and placed inside and facing the *mihrab*. The SS1 location was chosen based on the typical *Imam* praying position. The measurement points were taken along

straight line from the *mihrab* location as show in Figure 1. Similar measurements were conducted using PC-based measuring system for RT, C_{50} and STI at each selected measurement points.

4. RESULTS AND DISCUSSIONS

4.1 BN and NC results

Table 2 shows the spatial minimum, average and maximum values of SPL in A-weighting of BN and NC with and without fans operating for each main hall of mosque. To ensure convenient to the reader, a comparison of the BN and NC rating is presented in Figure 2.

Figure 2 depicts the BN values are mostly below than 40 dBA. However, the mosque referenced MT mosque shows the maximum value of SPL over than 60 dBA. The MT is near to the busy main road where the effects of traffic noise give significant influence to the result.

The NC ratings of measured BN indicate a *very quiet to quiet* environment except the MT mosque where the value (NC-49) indicates a *moderate noisy to noisy* environment. Furthermore, the NC ratings is higher when the fans in operating condition which all NC rating of the mosques fall under a *moderate noisy to noisy* environment. However, the preferences of NC rating are ranging between NC-25 to NC-30 based on condition in spaces such as conferences halls. It is should not be exceeded from NC-30 because the noise can interfere the speech delivered by *Imam*.

Table 2 - Summary of overall sound pressure level (SPL) and noise criterion (NC) of the mosques

No.	Mosque ref.	Overall SPL (dBA)						Noise Criterion (NC)	
		Fans OFF			Fans ON			Fans	
		Min	Ave	Max	Min	Ave	Max	OFF	ON
1	LA	35.1	38.1	42.5	54.8	59.8	55.5	26	47
2	BU	47.9	49.0	50.3	60.3	61.0	61.9	38	51
3	MT	56.1	58.5	61.6	60.1	61.3	62.5	49	51
4	KD	42.1	44.0	46.7	56.1	56.3	57.4	32	47
5	KK	43.0	45.3	49.7	57.7	57.9	58.4	29	48

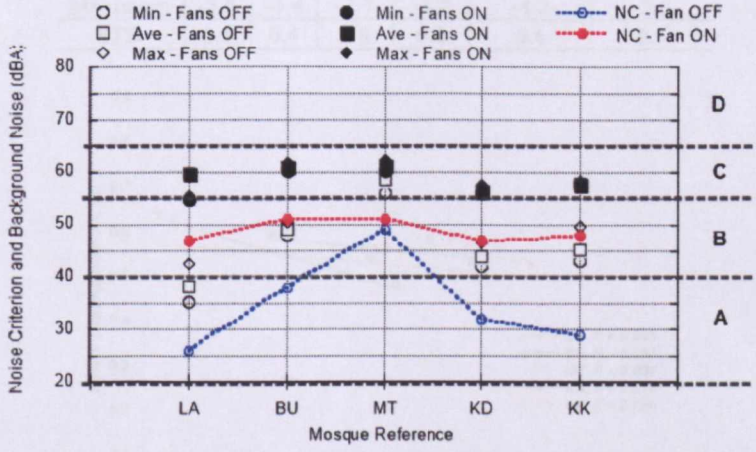

Figure 2 - A comparison of the BN and NC rating measured in mosques with and without operating fans. Rating for NC, A – "very quiet to quiet", B – "moderate noisy to noisy", C – 'very noisy" and D – "extremely noisy". (See Table 2)

4.2 RT and C50

It was possible to characterize the characteristics of room by measured the RT and C_{50} in different measurement points. Although the materials, shapes and the volume of the rooms give significant effects to the acoustical quality but these were not taking strictly into consideration in our first stage of study. The RTs of each point at different locations for all mosques are averaged and summarized in Table 3. The preferences of $RT_{500\ Hz}$ range for speech is approximately from 0.6 – 1.2 s depending on room's volume. However, below than 0.75 is preferable for the comfort of verbal communication. Most of the main halls exceeded the 0.75 s except the KD. Furthermore, the mosques show the higher RT when unoccupied but the values expected to be decreased when the mosques are fully occupied.

The spatial-averaged of C_{50}s of each point at different locations for all mosques are summarized in Table 4. The C_{50} values are varying from -5.3 to -3.9 dB. The most required value of C_{50} should be above 0 dB to represent good intelligibility in a room with normal reverberation. The mid-frequency of 500 – 1000 Hz shows -4.8 dB in averaged values.

Table 3 - Summary of overall reverberation time (RT) of the mosques

	Octave-band frequencies (Hz)				Average	
Mosque	250	500	1000	2000	500-1000	500-2000
LA	1.16	1.98	1.69	1.16	1.84	1.61
BU	1.40	0.99	0.52	0.86	0.76	0.79
MT	0.70	0.89	0.80	0.77	0.85	0.82
KD	0.92	0.78	0.50	0.79	0.64	0.69
KK	1.46	1.85	0.99	0.82	1.42	1.22
Minimum	0.70	0.78	0.50	0.77	0.64	0.69
Average	1.13	1.30	0.90	0.88	1.10	1.03
Maximum	1.46	1.98	1.69	1.16	1.84	1.61
STD	0.32	0.57	0.49	0.16	0.51	0.38

Table 4 - Summary of overall speech clarity (C_{50}) of the mosques

	Octave-band frequencies (Hz)				Average	
Mosque	250	500	1000	2000	500-1000	500-2000
LA	-3.9	-4.7	-3.7	-3.4	-4.2	-3.9
BU	-5.4	-4.5	-6.0	-4.4	-5.3	-5.0
MT	-4.9	-5.4	-5.1	-4.7	-5.3	-5.1
KD	-4.0	-4.4	-4.9	-4.3	-4.7	-4.5
KK	-3.6	-4.8	-4.6	-3.6	-4.7	-4.3
Minimum	-5.4	-5.4	-6.0	-4.7	-5.3	-5.1
Average	-4.4	-4.8	-4.9	-4.1	-4.8	-4.6
Maximum	-3.6	-4.4	-3.7	-3.4	-4.2	-3.9
STD	0.8	0.4	0.8	0.6	0.4	0.5

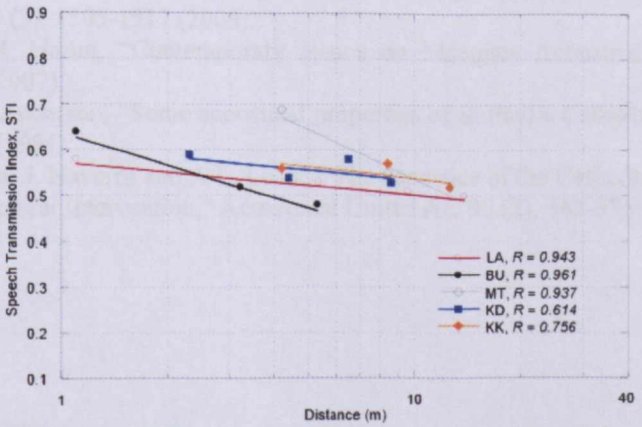

Figure 3: A comparison of measured STI with respect to measurement distance from sound source in all main halls in selected mosques.

4.3 STI

On the other hand, to reach high speech intelligibility the overall performance of the main hall is important. Figure 3 shows the comparison of STI values of each main hall of mosques with respect to distance from sound source. In general, the measured STI shows the basic tendency for their respective rooms relatively independent on the distance, that the longer the distance is, the lower the STI becomes. Furthermore, the fair performances of STI can be found in all mosques if the distance exceeded over than 15 m from the sound source. On the whole, the results of measured STI yield fair ratings to show the characteristics of speech transmission quality in all main halls at first stage of the study.

5. CONCLUSIONS

In this study, pilot measurements in five main halls of traditional vernacular mosques have been performed. A series of measurement revealed that the operating facilities in mosques resulting higher rating NC-49 which is reducing the performance of speech intelligibility. The evaluation on the mosque's acoustical quality offer fair performances in RT and STI. However, the low resulting in spatial-averaged of C_{50} need to be taken into consideration for increasing intelligibility speech level during all activities performed in the mosque. However, this phenomenon indicates the used of SRS might be an effective way to improve the intelligibility of speech. Further investigations and comparative simulations are now being pursued intensively.

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